AD-A154 686 RIVER TOW NEEDS FOR MANEUVERING ROOM ON THE UPPER MISSISSIPPI RIVER(U) COAST GUARD WASHINGTON DC OFFICE OF RESEARCH AND DEVELOPMENT APR 85 USCG-D-24-84 1/1

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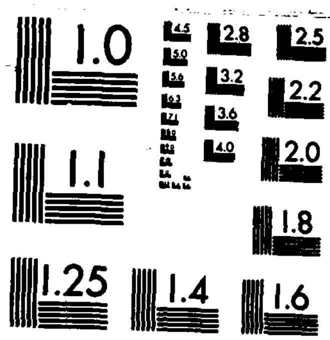

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Report No. CG D 24 84

AD-A154 686

River Tow Needs for Maneuvering Room on the Upper Mississippi River

APRIL 1985

U. S. Department of Defense
United States Army Corps of Engineers
Waterway Experiment Station Vicksburg, MS 39180

U. S. Department of Transportation
United States Coast Guard
Office of Research and Development Washington, DC 20593

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15. Supplementary Notes

This report is a project summary describing the preparation and conduct of a simulator experiment in tow maneuvering on the Upper Mississippi River.

16. Abstract

This report is a project summary describing the preparation and conduct of a simulator experiment in tow maneuvering on the Upper Mississippi River. The experiment was designed to determine whether substantial risk reduction benefits could be achieved with some amount of additional maintenance dredging in the Upper Mississippi River. It was stimulated by concern that safety would decrease with a change in dredging policy that would effectively reduce the channel dimensions.

The study was limited to a single 4.5 mile area below Wabasha, Minnesota, from mile 755.5 to 760 in low water, high flow rate conditions. Two river pilots each made twenty runs under various controlling channel dimensions: widths of 300 feet versus 400 feet and depths of 11 feet versus 13 feet.

The findings clearly indicate that substantial reductions of grounding risk would result from maintaining the channel at not less than 400 foot width in bends. For the river area examined, this would require relatively modest increases in dredging, and would not require any changes in dredging regulations.

This study did not fully examine effects of two way traffic or significant channel deepening.

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River towboats, Maneuvering, Channel design, Simulation, Marine Simulators, Hydrodynamics, Dredging, Marine Safety, Mississippi River	Unlimited

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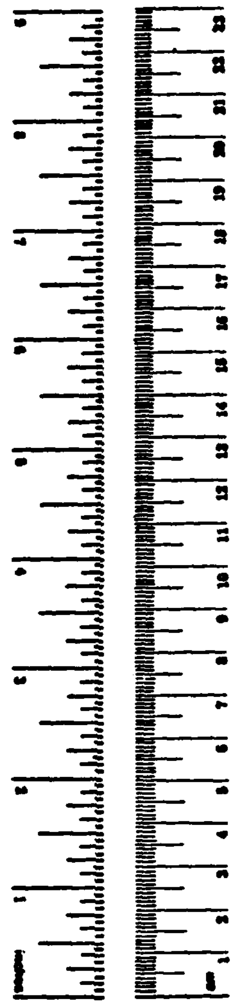
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

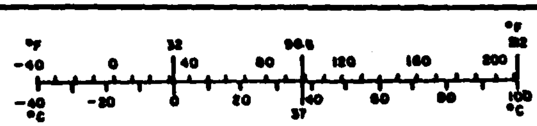
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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RIVER TOW NEEDS FOR MANEUVERING ROOM ON THE UPPER MISSISSIPPI RIVER

This is a summary report of a research study done in 1983 and 1984 by the U.S. Army Corps of Engineers, the U.S. Coast Guard, and Tracor Hydronautics, Inc. For more information, see report CG-D-16-84, Miller, E.R. and Barr, R.A., Effects of Alternate Channel Configurations on Navigation in the Upper Mississippi River, July 1984. It is available from the National Technical Information Service, Springfield, VA 22161, as accession number AD A150 155.

The Setting:

Coal, oil and petroleum products, fertilizer, chemicals, ore, and grain are some of the bulk cargoes that are carried daily in river barges. River transportation has been economically important to the development and economic health of the middle half of the U.S.A., from the Canadian border to the Gulf of Mexico, for most of our country's history. Reliable river transportation requires channels to be wide and deep enough for tows (towboats and the barges they push) to navigate the river safely.

Safe navigation is threatened by sediment deposits. Rain washes fine dirt and sand off the land into streams and rivers. High water flows during spring snowmelt or periods of heavy rains erode material from the river banks. This dirt, sand, and eroded bank material is deposited as sediment along the river at locations depending on the water flows and shape of the channel. If natural processes are left to themselves, rivers re-route themselves over time, preventing dependable navigation.

Most significant navigable rivers in this country have some type of control device or devices to limit this major shifting and changing of the river channel. These devices may include revetments, dikes, and navigation locks and dams. It is the responsibility of the U. S. Army Corps of Engineers to control the Upper Mississippi River and other navigable rivers to reduce flooding and to maintain navigation.

One of the most important controls on the Upper Mississippi River is a series of locks and dams. The dams block the river flow and create pools of water. Gates or other outlets at each dam allow officials to adjust the flow of water past the dam to keep the river at a more dependable depth and flow rate than would occur naturally.

Revetments are used along the river banks to limit or eliminate bank erosion. This reduces the amount of sediment carried off by high flows, and hence the amount available to be deposited when the flow is low. Bank protection also keeps the river flow from eating away the outside of curves, thus preserving waterfront property and reducing the meandering tendency of the river.

Dikes or "wing dams" are used to force the water to flow in a more limited portion of the channel during low flow periods, as compared to high flow conditions. These dikes are long, thin, low structures like small dams that extend out from (or are parallel to) the bank and limit the flow rates against the bank. During high flow periods, the water can flow over these low dikes. By forcing the lower flows into the limited channel between dikes, the water there is kept moving fast enough so that sediments are carried along rather than settling to the bottom. Over several navigation seasons, with their alternating high-water and low-water periods, some sediments are trapped around the dikes, further reducing the amount of material available to interfere with low-water navigation. Successful use of dikes requires great skill and depends heavily on the particular local conditions. Critical factors include, among others, the size and type of sediment, whether the location has a tendency to extreme floods, and whether it tends to have extended periods of extremely low water.

Although sedimentation of channels is greatly reduced by effective controls, sediments may build up seasonally in certain parts of the river channels, making them shallow and narrow. Some dikes and revetments were designed for channel conditions which have since changed, making those structures ineffective. Where the river does not maintain itself even with the aid of flow-regulating structures, if the channel ceases to be safely navigable by tows carrying their normal amounts of cargo, the excess sediments must be removed physically.

Physical removal of excess sediments is called "dredging" and involves several problems. Dredging is very expensive. The presence of a dredge in the channel takes up navigation room needed by the tows. Another problem is where to put the material that is removed. If placed back in the river, it may disturb the aquatic environment, and it will tend to move and cause another problem downstream. Putting it on land is much more expensive, and there are concerns that it will disrupt the ecology by burying mating and nesting areas for various birds, insects, and small animals. Accordingly, the Corps of Engineers limits dredging to what is necessary for safe and efficient navigation, to the extent the needs are well understood.

The Research Problem in This Study:

This study sought to distinguish more clearly than before between inadequate channels and adequate channels for safe and efficient tow navigation. Improving the understanding of this distinction is intended to help the Corps of Engineers determine: whether existing channels are adequate and, if not, what is the minimal additional dredging needed to make them adequate. This study does not establish the minimum dredging requirements in itself, but it does provide important new insights that can be used along with previous channel design criteria and other research results to improve the state of the art of making dredging decisions.

Determining the adequacy of river channels is complex; it starts from considering the sizes and static positions of the tows within the channel at the various angles they may assume over time. Next, dynamic effects of the river currents, the nature of the movements of individual tows, and the interactions among tows in two-way traffic come into play. Finally, attention must be paid to the human factors; pilots use various control strategies, which increases the variability of tow dynamics beyond just the environmental effects. Until recently, there has been no scientific method of studying all of these elements at the same time in safe experiments. The modern technology of marine simulators, and especially low-cost simulators, now allows direct examination of this problem.

Figure 1 shows a time sequence picture of a tow maneuvering in a winding river. It can readily be seen that the tow needs a channel wider than its own width. Less obviously, but adding to the width needed, the tow pivots, about a point toward its front end and tends to slide sideways when turning sharply. River currents have an important effect on the manner in which a tow turns and, therefore, on how much channel width is needed. The Corps of Engineers Engineer Manual EM1110-2-1611, entitled "Layout and Design of Shallow Draft Waterways" provides general guidance for design of such channels. The guidance is more complete about the widths needed than about the depths, due to lack of enough good data on depth requirements.

This design guidance came out after the Upper Mississippi River navigation channels were completed, and many existing channel segments do not meet the channel width guidelines. Basically, the design manual recommends widths of 300 feet for "straight" reaches of two-way traffic with 105-foot wide tows. Extra channel width must be provided in "bends."

Analysis shows that the only reaches that can be called straight are exactly that; they display no curvature whatever. Obviously, in small radius ("sharp") bends, the tow must sometimes be at a large angle relative to the channel. That requires the channel to be very much wider than the tow. It is less obvious, but equally true, that in very large radius bends (which appear practically straight) the tow is forced to set itself at an angle of at least two to three degrees from its direction of travel. This requires a minimum of 45 to 65 additional feet of channel width for each of two passing 1200-foot long tows (a tow size which is routine on the Upper Mississippi River.) Thus, static geometry alone indicates that these channels should be at least 400 feet wide, except in those very rare segments which are perfectly straight.

Generally, maneuvering performance of tows is affected by the depth of water under the vessel as well as the clearance from the tow to the river bank. Because depth and width have interrelated effects on tows, variations in depth can affect the required channel widths. Prior to this study, however, no information was available to indicate how much the maneuvering performance was affected nor what effect alternative depths would have on needs for channel widths.

Note: Movement starts at the upper right and proceeds to the lower left.

Figure 1 Time Sequence Photo Mosaic of a River Tow Maneuvering through a Winding River

Inadequate knowledge of the channel dimensions needed for safe navigation has tended to lead to conflicts over concerns with the environmental and dollar costs of dredging versus concerns for navigational safety and the possible environmental consequences of unsafe navigation. In general, the deeper and wider the channel, the better for navigation, maneuvering, and towboat operating efficiency. In general, the shallower and narrower the channel, the less dredging is required to maintain it. The problem becomes, "What is the proper balance of these requirements, and what are the minimum channel dimensions required for safe movement of tows through the river?"

There are a lot of other interests besides towing companies who are - and should be - interested in the safety and efficiency of river tow operations. Recreational boaters share the river with the commercial tows, often operating dangerously close to the tows and often apparently unaware of the great distances needed to stop, or even slow, a large, loaded, downbound vessel. Daily, numerous potential accident situations arise. The less room there is for the tows to maneuver, the greater the danger to boaters who happen to get in their way.

Apart from the danger to boaters, even if only the towboat and barges are involved, accidents can be severe. Although most barges carry harmless ore, grain, coal, and other safe cargoes, there is still a certain amount of gasoline, fuel oil, and other hazardous chemicals in the barge traffic. If those barge loads of hazardous cargo are spilled, severe dangers can arise. Flammable spills could drift into docks, marinas and industrial facilities for thousands of yards along the river. Some spilled liquid chemicals could kill fish for miles down the river, and also threaten drinking water reservoirs and farm irrigation systems. Other chemicals quickly turn into toxic gases if they are spilled. One accident in Louisville, Kentucky in 1972 threatened tens of thousands of residents with clouds of lethal chlorine gas. That threat came from nearly spilling just one barge load of liquid chlorine.

As long as the historic level of safety is not seriously degraded, there is no major cause for alarm. Dangerous cargoes are handled with special care, and excellent safety records have been maintained. Nonetheless, any progressive degradation of the channel endangers that safety record.

The safety concerns have to be balanced against concerns for operational efficiency. If we did not care about economics, we could do without towboat operations, allow fewer tows and barges on the river, or require each individual tow to be smaller than the maximum 105 foot by 1200 foot tow with 9 foot loaded draft now common on the Upper Mississippi River.

If towboats and barges were smaller - or if fewer of them were used in a single tow - smaller channels might be sufficient. At the same time, costs of transportation would increase dramatically. Thousands of farmers in the midwest would have to pay more to get their fertilizer shipped upriver and their grain shipped downriver. Many industries would have to pay more to have their fuel shipped upriver and their products shipped downriver. Ultimately, consumers and taxpayers would have to bear these costs.

Given that large tows have operated fairly safely for years, there is little reason to change their size or configuration. The change that causes concern is a progressive deterioration of the navigation channel dimensions within a political and economic environment that minimizes dredging. Given the potential for ecological disruption mentioned earlier, each instance of dredging must be justified. Even in places where the channel widths do not meet modern design guidelines, channel widening has been hard to justify without firm evidence that the existing channels are dangerous.

Towboat operators have been concerned that many channel areas on the Upper Mississippi River are dangerous and becoming more so because of progressive sedimentation and limited dredging. They perceive that close calls with recreational boats and the chances of just running aground are increasing. Since the industry position almost always favors deeper and wider channels for economic as well as safety reasons, some way is needed to measure objectively the danger, if any, to towboats which is directly caused by existing channel dimensions.

The Research Study and Its Sponsors:

The U.S. Coast Guard is the federal agency charged with operational navigation safety. Its Second District Office in St. Louis is charged with maintaining aids to navigation and safe traffic rules on the Mississippi and other rivers. Officials there share the concerns expressed by industry. They offered to cooperate with the Corps to try to relieve this problem.

The St. Paul District of the Army Corps of Engineers performs the channel maintenance on the Upper Mississippi and other rivers in the area. They provided the funding for this study, which is one of several efforts to define how the width and depth of river channels affect navigation.

The Waterways Experiment Station in Vicksburg, Mississippi is the research arm of the Corps which is most knowledgeable of the technological aspects of river management. Their Hydraulics Laboratory accepted this study from the St. Paul District.

The Hydraulics Laboratory realized that they would need more precise scientific data about details of how tows move through the water to complete the study. Under contract to the Coast Guard and the Corps of Engineers, Tracor Hydronautics, Inc. in Laurel, Maryland had been conducting highly sophisticated tests on scale model tows and had also developed a very efficient type of simulator for mathematical and operational analyses of towboat problems. One such simulator is at the Hydraulics Laboratory; another is in the Office of Marine Environment and Systems at Coast Guard Headquarters.

All of these offices decided to pool their efforts. Project management was assigned to Coast Guard Research and Development, but the bulk of the decisions were made at informal meetings of people representing all the interests mentioned above.

There were three distinct technical aspects of the study: the tow movements, the river hydraulics, and the human factors of tow operations under pilot control. The first need was for a highly accurate mathematical description of the dynamics of an Upper Mississippi River towboat and barges in shallow water, deeper water, and various conditions of channel bottom and channel sides.

This mathematical description had to come from precise scale model tests in a specialized model basin, equipped with a large amplitude planar motion mechanism, and capable of shallow water testing. Figure 2 shows this facility at the Tracor Hydronautics Ship Model Basin. In hopes that such expensive tests could be avoided in some future research, efforts were made to estimate the needed data using hydrodynamic ("movement in water") theory with towboat and barge dimensions. Later, these estimates were compared to the model test data.

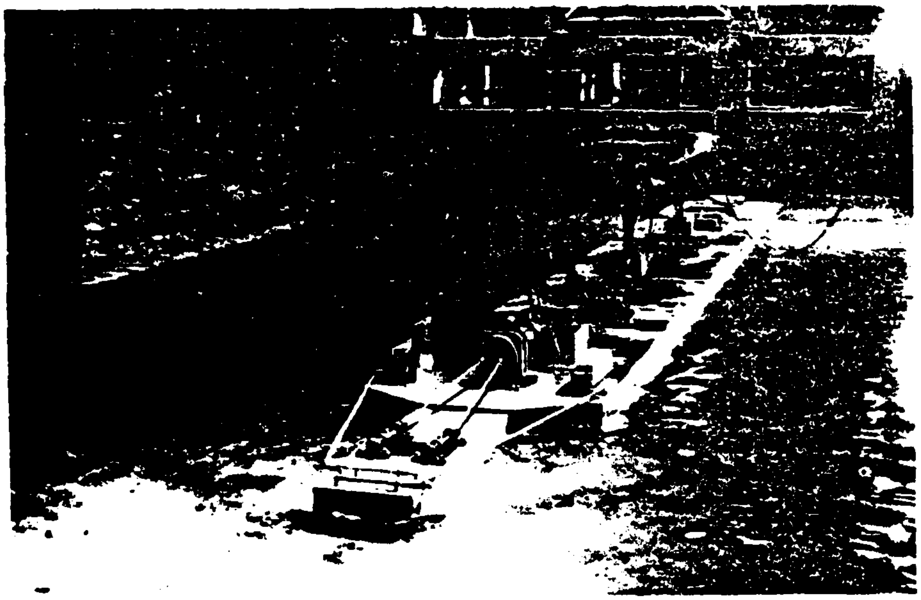
The results of the hydrodynamic studies were as follows:

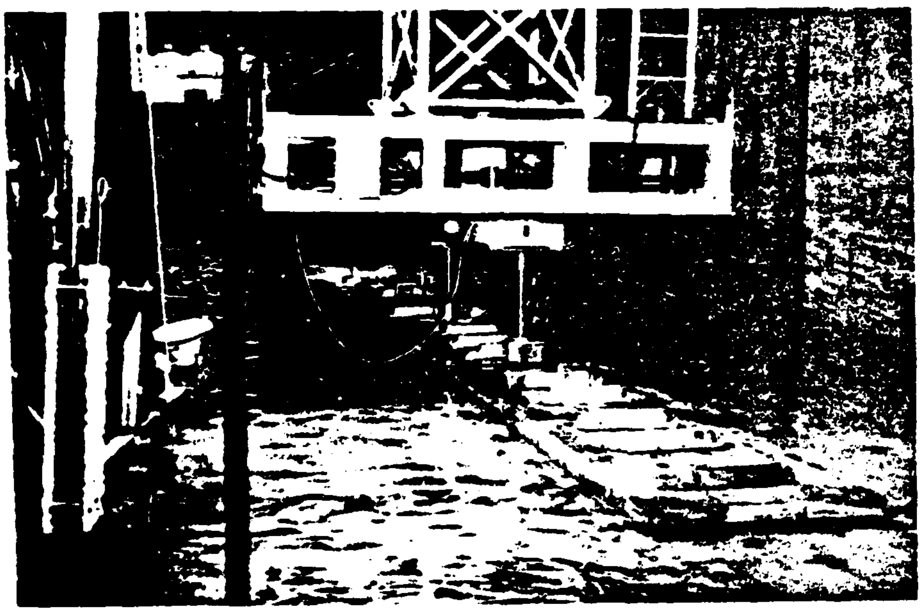
1. Estimation works fairly well for tows operating in deep water, but poorly for tows in shallow water. Not enough information has been accumulated about such operations. Because tows operate mostly in shallow water, we must rely on model tests to understand tow movements. We are hopeful that more complete and accurate theoretical understanding will be reached through further research, so that expensive testing requirements can be reduced.

2. The model test results led to mathematical models that were highly successful - but not perfect - in the simulator. That is, most of the complex motions of a towboat pushing fifteen loaded barges could be reproduced faithfully in a computer-based simulation. Effects of sudden application of full power ahead or astern in very shallow water are examples of the things we could not model properly. Pilots avoid such maneuvers in real life, so we simply asked them to avoid these maneuvers on the simulator also. That kept the simulations realistic.

One major limitation that was not fully overcome was our inability to model tows passing, upbound and downbound, as is very common in real life. Our partial solution was to model a stationery upbound towboat in just one location in the study area. Often, but not always, the upbound tow does stop while the downbound tow passes.

Another needed input to the simulation, besides good hydrodynamic data, was good river hydraulic data. The Hydraulics Laboratory at the Waterways Experiment Station developed mathematical representations of a four and a half mile river section for this study. (The river section ran from Wabasha, Minnesota down to a point just above Lock and Dam Four.) These mathematical models allowed the computer to depict in some detail the flow patterns and channel dimensions that would occur in that river section under four different assumptions about the amount of dredging to be done. The model results for a 300 foot X 11 foot channel compared well to measurements made by the Army Engineers, St. Paul District, of conditions that existed on the river at the time the study was conducted.





ıre 2 Model Towboat and Fifteen Barge Tow, Tracor Hydronautics Ship Model Basin, Laurel, MD

stationary tow was modeled, the results described here may not be fully applicable for two-way, dynamic traffic conditions. It should be noted that the tow pilots typically select wide places in the river for passing. The upbound tow waits to avoid having to pass in the narrow, constricted sections of the river. Pilots stated that they normally would not choose to pass at the traffic tow location modeled in this experiment. The test was included nonetheless because pilots sometimes cannot exercise their preference due to a lack of adequate communications.

One section of river was modeled (a length of 4.5 miles running downstream from Wabasha, Minnesota almost to Lock and Dam Four.) This section of river had relatively short stretches of minimum depths in the navigation channel. Other waterways with substantially longer minimal depth areas, such as the Gulf Intracoastal Waterway, might experience greater benefits from maintaining a deeper channel. The reach tested was agreed to be representative of the Upper Mississippi River channel types subject to the dredging policy issues that led to the interest in this study.

Finally, only two experienced pilots were used. They showed considerable variability in their control strategies. The question has been raised as to whether more pilots need to be included in this study. The answer is: not in this exact same experiment. Each pilot's maneuvering performance was better in the wider shallow channel than in the narrow deep channel. This is due to characteristics of the study area, rather than to individual pilot control strategies. For that reason, repeating runs through this area with additional similar pilots could only be expected to confirm these results.

Even with less experienced pilots added to the sample, the direction of change in maneuvering results due to channel dimensions could not be expected to change, although more simulated groundings and close calls might occur.

It is possible that the benefits of deeper dredging are understated due to the study area selected. To test that possibility, a similar simulator experiment might be conducted in a river area with large contiguous channel segments at a relatively constant, shallow depth. Properly designed, such an experiment could replicate the width tests of this study and also examine the safety effects of channel width in high flow conditions.

Conclusions:

For the river area studied, a significant improvement in operating safety could be obtained by maintaining a minimum 400 foot channel width in bends, even with no change to the maintained depth of 11 feet. Additional dredging would be needed, but much less than that required for maintaining a deeper channel of 13 feet. No change in authorization would be needed for such a change in maintenance dredging policy. No intermediate controlling widths between 300 feet and 400 feet were investigated in this study. As noted on page 3, an analytic case can be made for a 400 foot width in wide radius bends; greater width would be needed in smaller radius (tight) bends.

While a width-only improvement could reduce the risk of accidents significantly, it would not otherwise improve operational efficiency. On the other hand, maintaining a deeper navigation channel would allow pilots to make better time in the safer reaches at some cost in added fuel consumption. As with other modes of transportation, added speed is often worth the added fuel expense. Only deepening the channel, without widening it, should not be expected to improve safety.

Maintaining both a wider and deeper channel than the baseline case in this study would make major improvements in operational safety and small improvements in economic efficiency. It would also require substantial increases in dredging.

Estimated Validity and Limitations of the Study:

The authors consider these conclusions valid for much of the Upper Mississippi River in conditions of low water and relatively high currents during such low water conditions. These are the limiting conditions for those maneuverability problems involving dredged depths.

A different maneuverability problem exists during the highest water and fastest current conditions. Increases in the maintained channel width may be even more important during those flows. It is more difficult to control a tow in bends when currents are high even if the water is very deep. That condition was not tested in this study; however, it is known from previous physical model studies that the tows require more maneuvering room (that is, have a larger angle with respect to the channel) while going through the same curve in faster currents as opposed to slower currents.

Only one towboat and tow configuration was modeled in this study, even though many different towboat designs and tow configurations are used on the river. The towboat selected (140 feet by 38 feet with 3900 nominal shaft horsepower) is considered representative of those operating on the Upper Mississippi River and is typical of the size and configuration most successfully used in transiting the locks on this river.

The dynamics of two way traffic could not be modeled. In partial compensation, an upbound tow was stationary in the channel just above Crat's Island. Several groundings and close calls occurred just below this tow in the narrow channel conditions. This indicates that two way traffic is a significant factor in dredged width requirements. Because only one

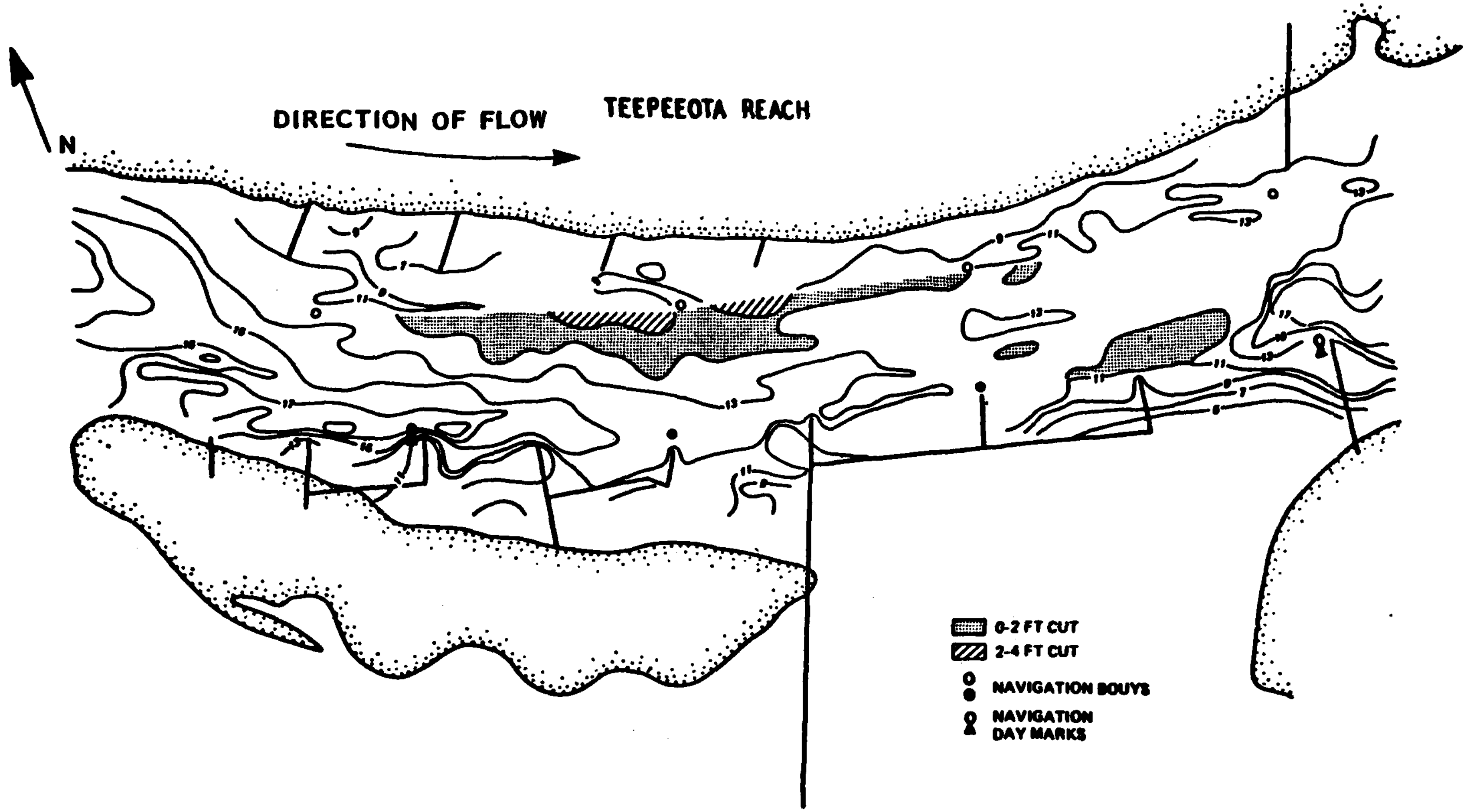


Figure 10 Dredging Needed for a 450 X 11 foot Channel

Teepeeota Reach

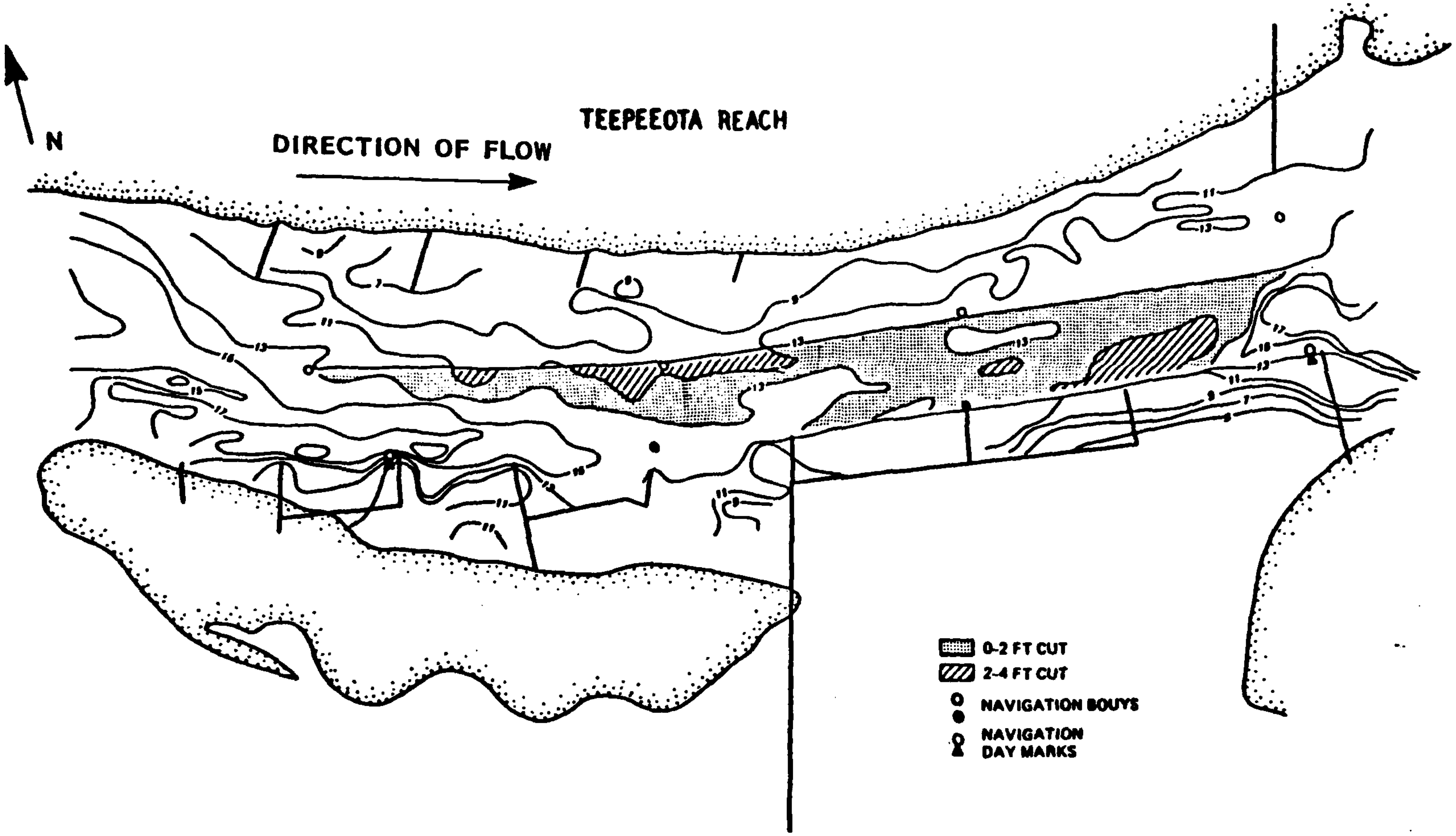


Figure 9 Dredging Needed for a 300 X 13 foot Channel Teepeeota Reach

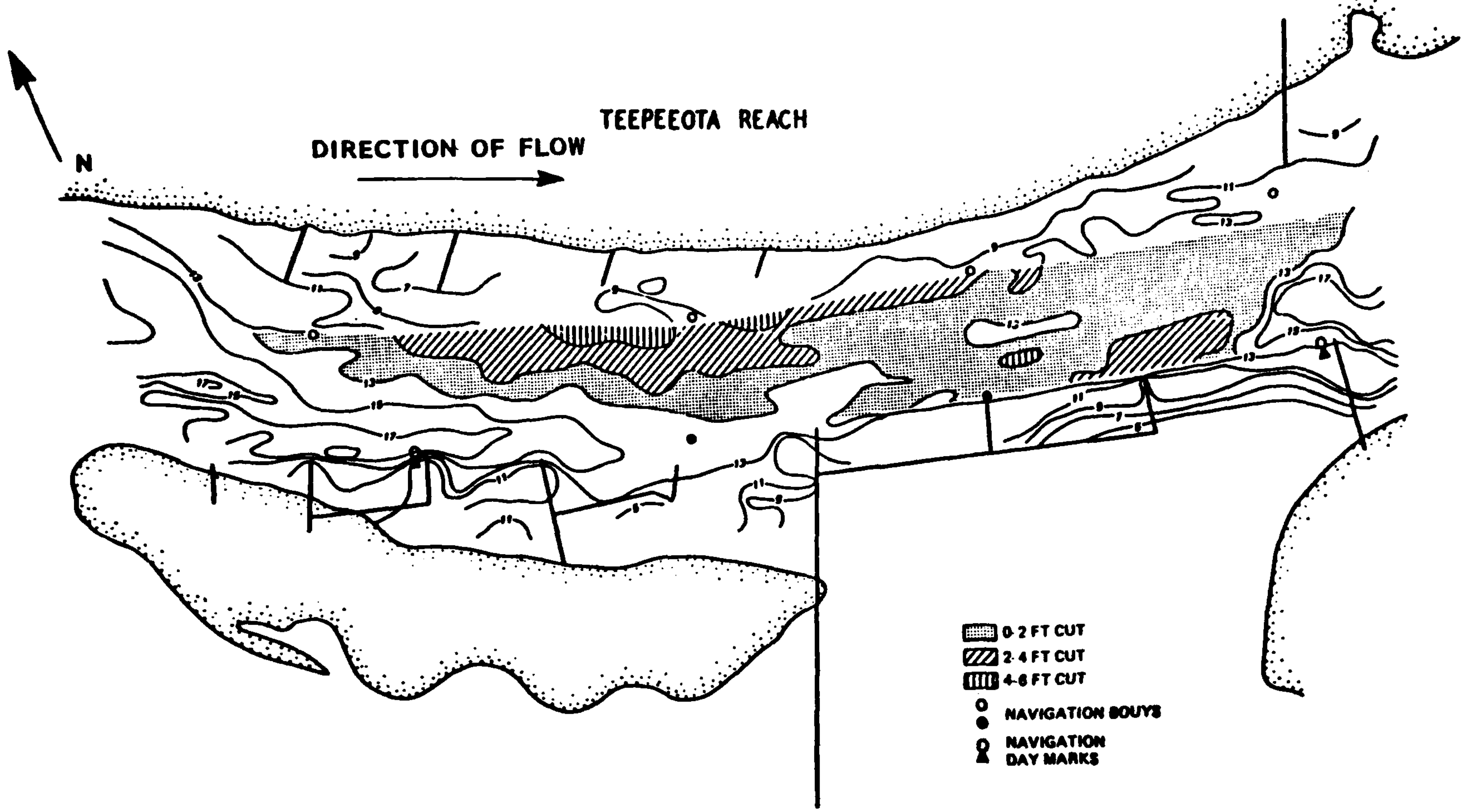


Figure 8 Dredging Needed for a 450 X 13 foot Channel
Teepeeota Reach

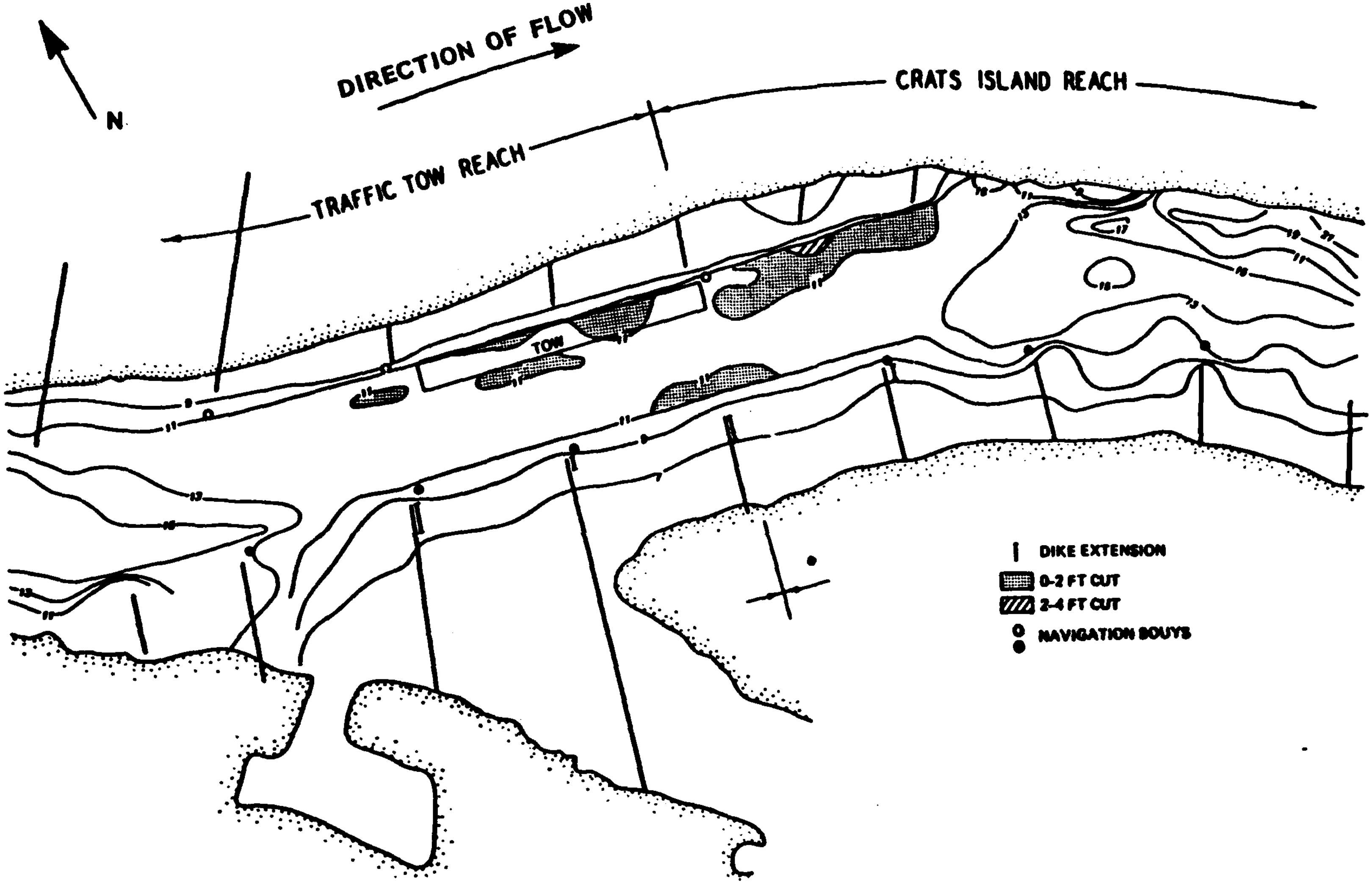


Figure 7 Dredging Needed for a 400 X 11 foot Channel Upper Reaches of the Study Area

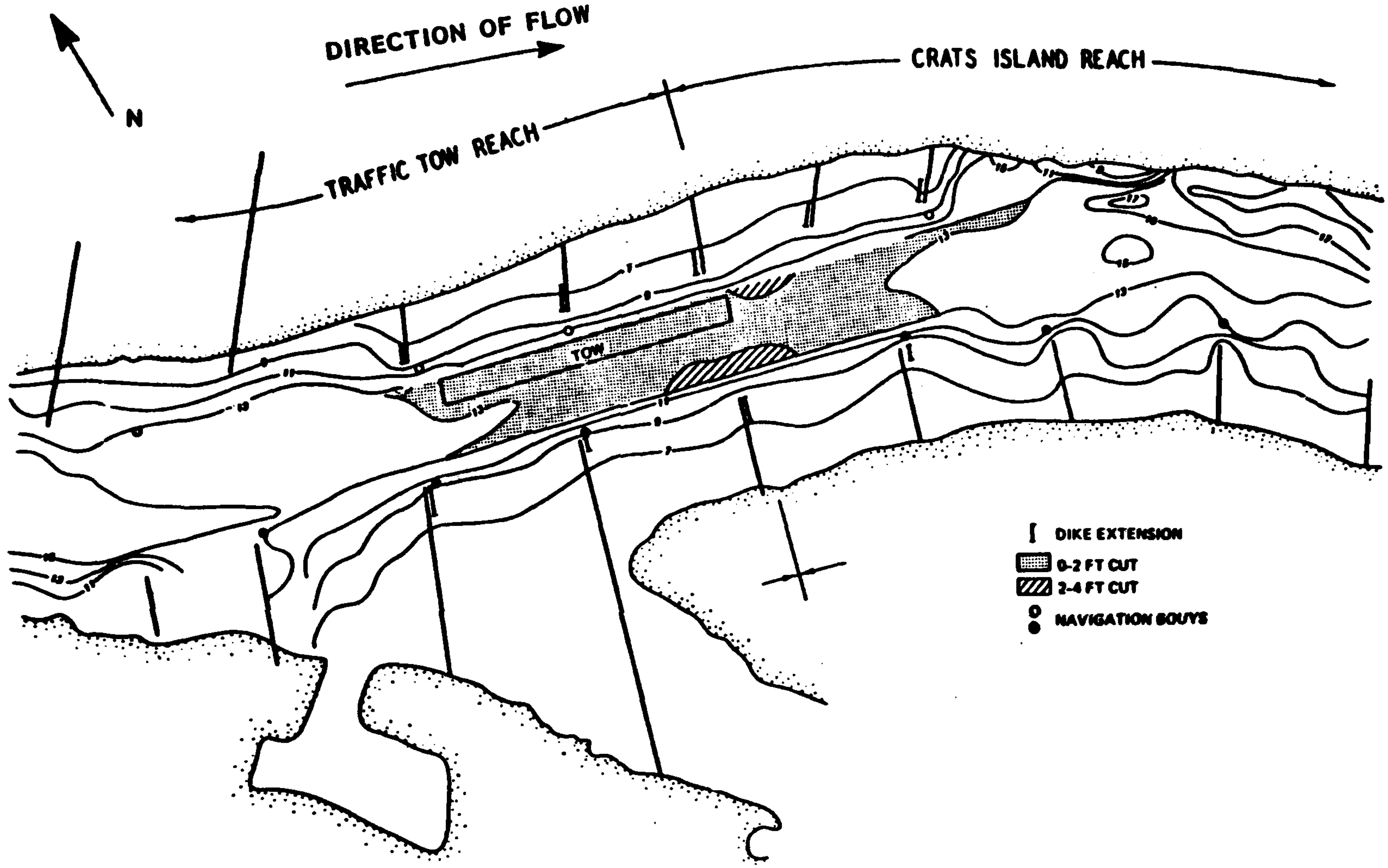


Figure 6 Dredging Needed for a 300 X 13 foot Channel
Upper Reaches of the Study Area

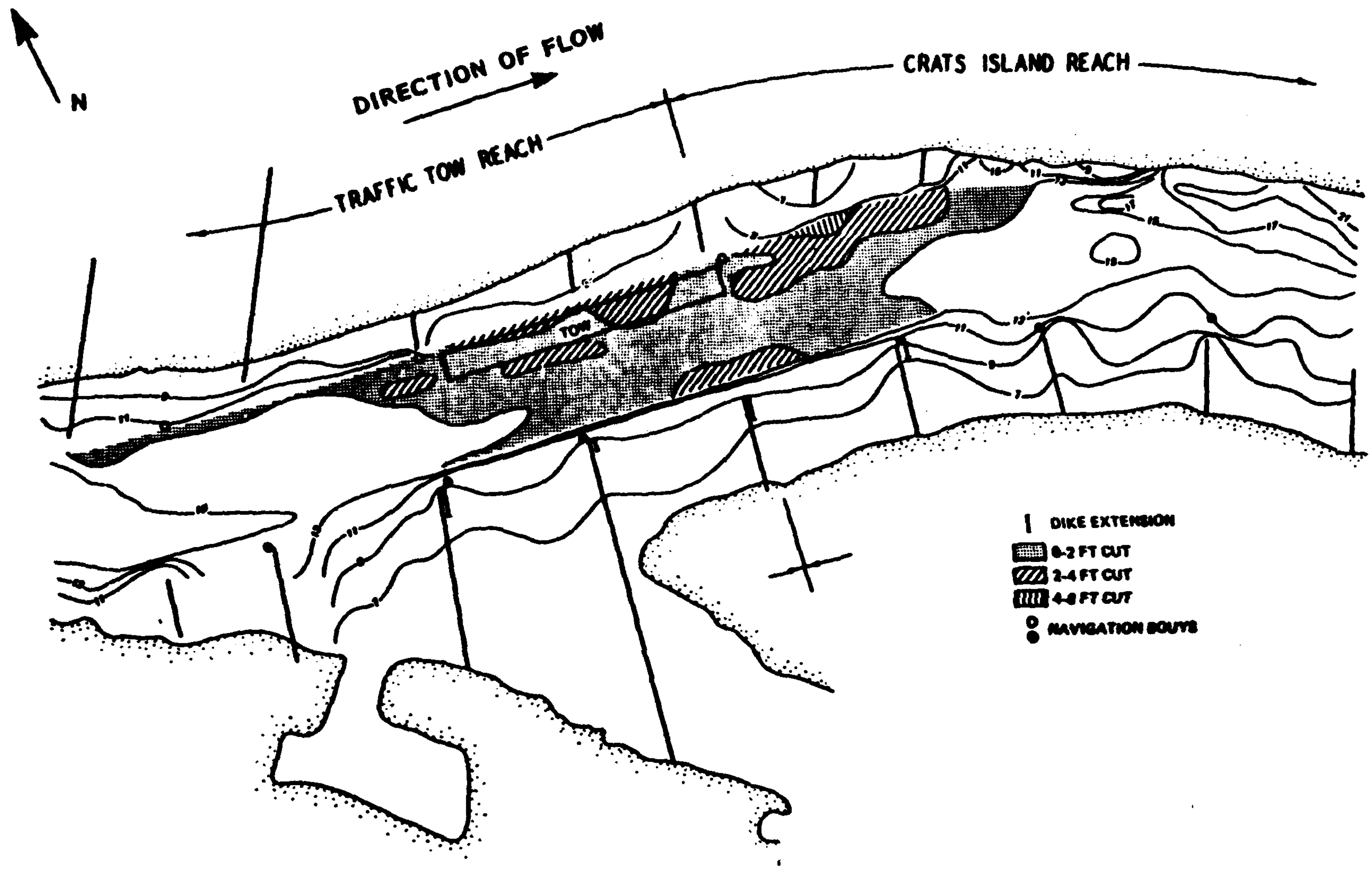


Figure 5 Dredging Needed for a 400 X 13 foot Channel
Upper Reaches of the Study Area

The net effect was faster tow movement with higher engine power in deeper channels downstream of Crats Island. In the case of the 400 X 13 foot channel, the still slow speeds in more dangerous reaches apparently saved fuel enough to compensate for the higher fuel use downstream.

The Answers: Dredging Requirements

As may be seen in Figures 5 through 10, the amounts of additional dredging needed to achieve channel dimensions of 300 x 13 feet or 400 x 13 feet are very substantial. Far less added dredging would be needed to keep the channel 400 feet wide x 11 feet deep in bends for the river sections studied. (One section was effectively straight and is not shown.)

The channel dimensions currently authorized by the U. S. Congress for the navigation channel in the Upper Mississippi River are 300 feet x 9 feet. The current dredging policy is to initiate dredging activities when the measured depth in the channel approaches 10.5 feet. By the time the dredging takes place some of this depth will be lost and the channel will be approaching the depth that must be maintained by law. Current dredging policy also calls for dredging to a depth of 11 feet to give time before the dredging must be done again. Authorization is provided to increase the maintained width beyond 300 feet in curved reaches of the river. How much wider is a function of the size of the tows using the channel, the sharpness of the curvature, the velocity of the currents, the smoothness or irregularity of the river's edge, and other factors.

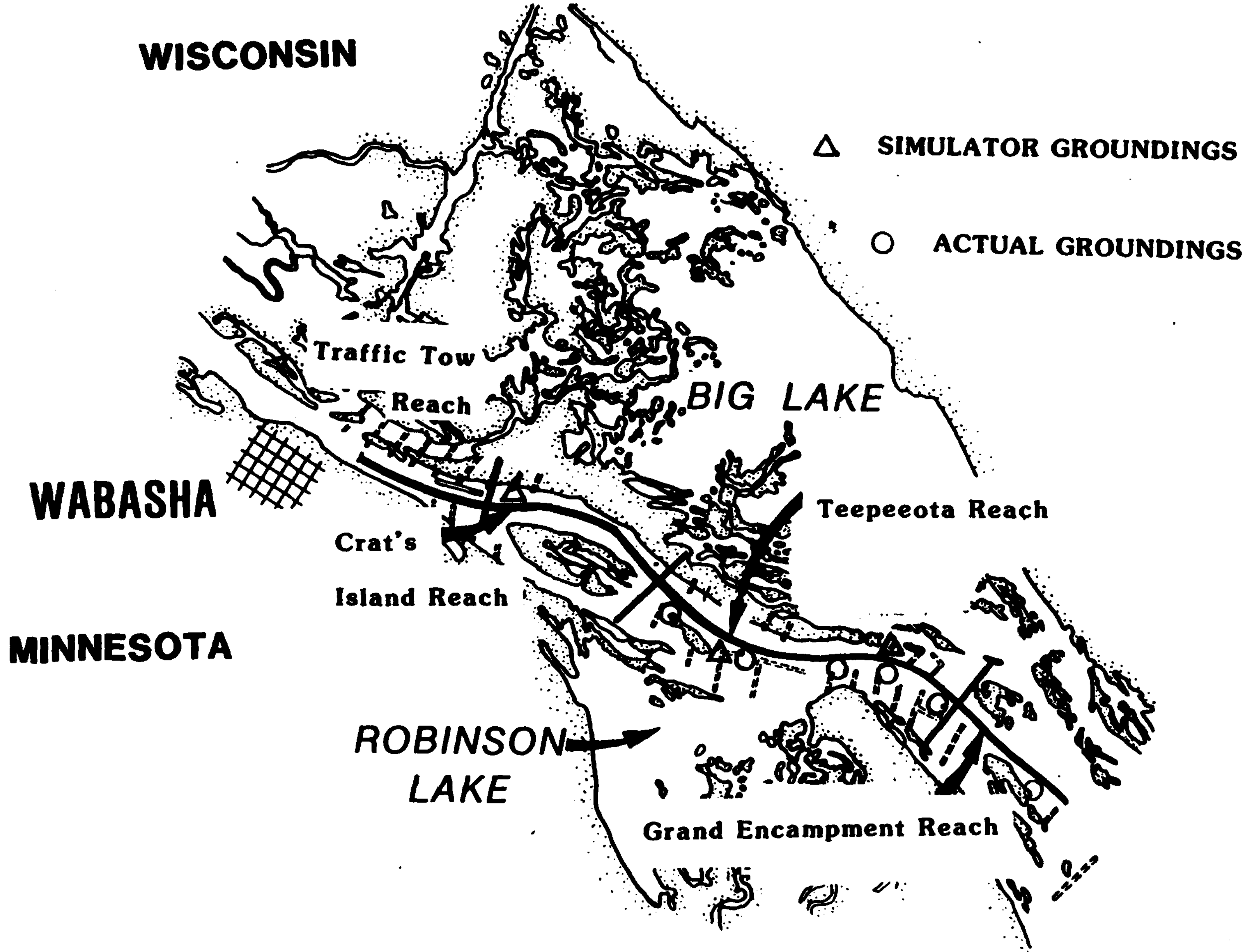


FIGURE 4 CHART OF THE STUDY AREA

Increasing both the depth and the width totally avoided even the reduced level of risk associated with the wide, shallow channel. This would, of course, substantially increase the dredging requirements relative to policy at the time of the study.

The groundings and close calls in the simulator study occurred at just three locations because only one river stage was studied, only a stationary traffic tow was encountered, and that traffic was always in the same precise location. In real operations, accident locations vary with the river stages, visibility conditions, where traffic is encountered, and due to other variables. Figure 4 shows the locations of simulator groundings and real world accidents from 1980 through 1984 in the study area.

The Answers: Economic Efficiency

Turning from safety to efficiency, we found quite different situations within the area studied. (See Figure 4.) In the "Traffic Tow" reach (above Crats Island) and in the "Crats Island" reach itself, no statistically significant differences in passage time or fuel economy were noted from one channel configuration to another. There was a lot of variation in these measures from run to run even in the same channel conditions.

Downstream from Crats Island, in the "Teepeota Point" and "Grand Encampment" reaches, there was a major effect of changing the depth but no effect from changing the width. In the deeper water cases, passage time was reduced by 11% as horsepower hours increased by 22%. Both changes were caused by increased engine power in these segments, whereas no comparable power increases were noted in the more dangerous reaches. Taking results from all four reaches together in each channel condition, the only significant finding was an 8% to 10% overall increase in fuel efficiency in the 400 X 13 foot case compared to the basic 300 X 11 foot case.

The triangles in Figure 4 show the points where the simulated tow came close to the bank or grounded. The pilot's control actions for avoiding these problems have to be taken correctly well ahead of time. For these downbound tows, the incidents plotted near the northern tip of Crat's Island relate to steering and engine control actions upstream. That is where our simulated stationary traffic tow was located. Maneuvering past the traffic tow limited the pilot's control options for his entry into the bend. In general, the asterisked locations of groundings are associated with control problems upstream of those points (for downbound tows.)

Understanding the delayed safety effects of control actions, we can see that where pilots were keenly aware of dangers - in the Traffic Tow and Crat's Island reaches - they did not use substantially more engine power in the deeper channels than in the shallow ones. Where they could feel more comfortable in deeper rather than shallower water - that is, after the first bend in the Teepeota Point reach - they tended to increase power when the controlling depth was 13 feet instead of 11 feet.

The Answers: Safety in Alternate Channel Situations

The most difficult and dangerous situation studied was the case of the recreational boat blocking the channel. In that situation, both pilots experienced groundings and near groundings in the narrow channel. No similar experiments were run with a wide channel because it was obvious there would be no serious maneuvering problem from a single boat in that case. Dangerous multiple-boat encounters are infrequent.

Apart from the emergency scenario, operating the tow was most dangerous and difficult in the tightest channel - 300 feet by 11 feet controlling dimensions. That channel is most like the existing one, as shown by the detailed Corps survey mentioned earlier.

For the scenarios without the recreational boat emergency, the most sensitive risk measures were groundings, unintentional approaches within 25 feet of the channel boundary, and frequent use of full rudder in bends. Table 1 summarizes these measures.

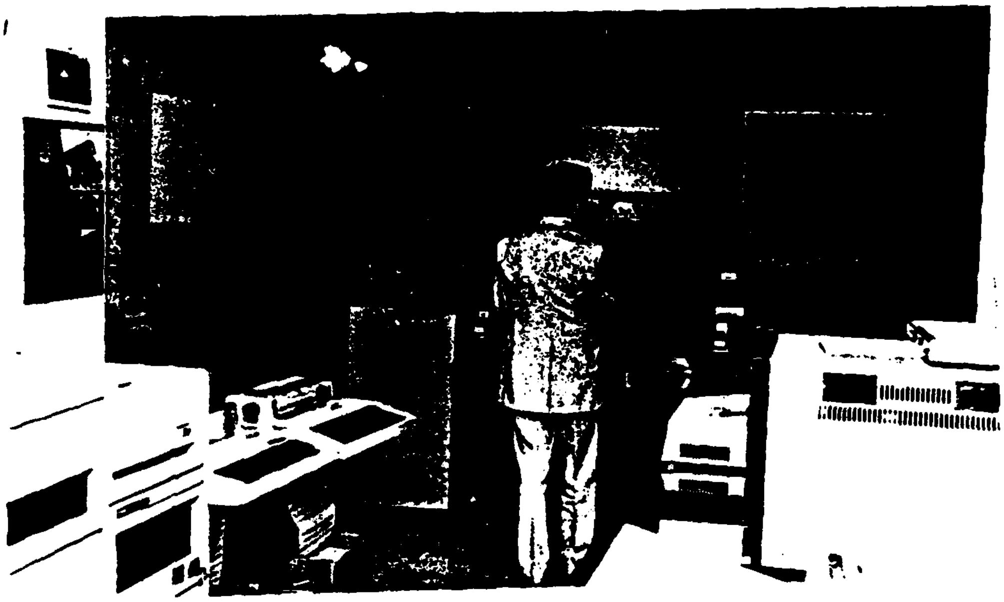
TABLE 1 CHANNEL DIMENSIONS AND THEIR RISK MEASURES

Channel	Number of Groundings	Number of Close Approaches	Full Rudder Use in Bends
300 x 11	3	6	High
300 x 13	3	11	High
400 x 11	NONE	1	High
400 x 13	NONE	NONE	Low

The relative changes from one channel to another in Table 1 are consistent with the subjective appraisals by the pilots. They were also confirmed by other measures of navigational safety such as percent of available channel width taken up by the tow. (The pilots did not necessarily agree that approaching within 25 feet of the bank indicates danger, because such approaches are often made deliberately under controlled conditions. This measure appeared to the researchers to be useful in this study, however, because the pilots normally maintained greater clearances whenever possible in these experimental runs. Also, this measure was found to correlate well with other measures of difficulty and danger.)

A slight reduction in the danger and difficulty was perceived by one pilot when the controlling depth increased to 13 feet, leaving the width at 300 feet. The other pilot indicated that the deeper narrow channel was <u>more</u> difficult and dangerous than the shallower narrow channel. Objectively, the same number of groundings and even more close approaches to the bank were recorded in the 300 X 13 foot channel compared to the 300 X 11 foot channel.

Increasing the controlling width of the channel bends to 400 feet (450 feet at one sharp bend) while leaving the depth at 11 feet was very effective in improving the ease and safety of navigation, but still left some risk. That residual risk was shown (in Table 1) by one close approach to the bank and by frequent use of full rudder in bends, which reduces the ability to cope with additional problems like recreational boats.



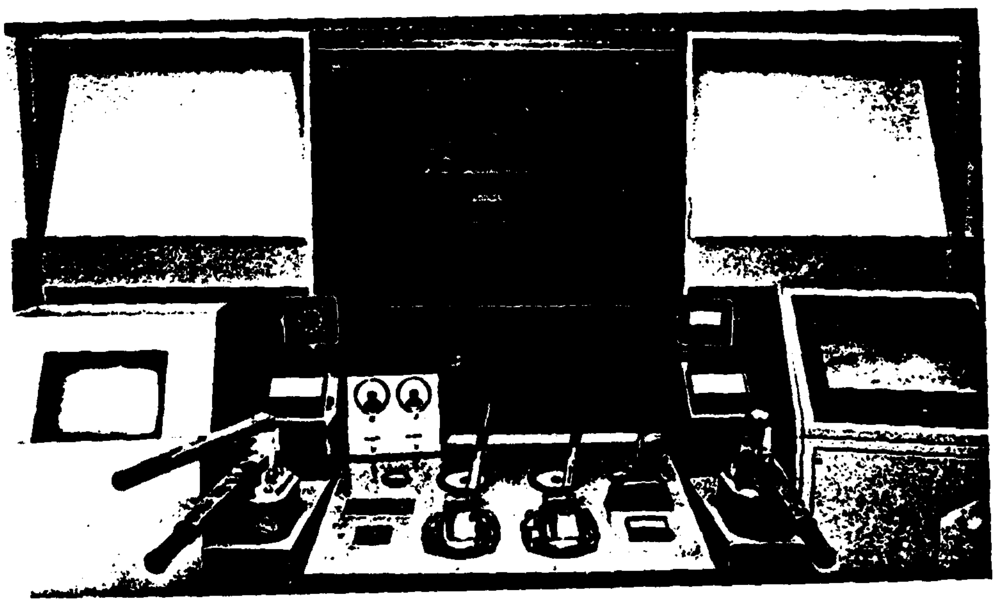


Figure 3 Maneuvering Simulator, U. S. Coast Guard Headquarters, Washington, DC

The Waterways Experiment Station took videotape pictures of the river segment to be simulated. Those pictures were used by Tracor Hydronautics and Coast Guard Headquarters staff to program computer generated imagery. The simulator is designed so that a river pilot can sit at a control station like one that might be found on a towboat. A forty-five inch television screen displays a picture like the river seen from the towboat window. Figure 3 shows the simulator.

Two well-qualified river towboat pilots came to U.S. Coast Guard Headquarters in Washington, D.C. to operate the towboat simulator. Each pilot made four "runs" (trips) under each of five simulated situations. One situation was an emergency caused by a recreational boat standing in the middle of the channel. In attempting to maneuver around the boat, the tow was in serious danger of grounding.

Four non-emergency situations were simulated - with nominal controlling channel widths and depths (in feet) of 300 by 11, 400 by 13, 300 by 13, and 400 by 11. The order of the runs was randomized so that each pilot's increasing familiarity with the simulation would not bias the answers.

Each of the two towboat pilots spent about three days in Washington to complete the twenty runs. They answered three questions after each run:

How realistic was it?	(1 = unreal to 10 = very real)
How difficult was it?	(1 = very easy to 10 = very difficult)
How dangerous was it?	(1 = no danger to 10 = very dangerous)

We wanted to know whether it was very much more dangerous and difficult for towboats to operate in more confined channels than in wider and deeper channels. Similarly, we wanted to determine whether there was a significant danger due to recreational boats in the existing river situation, which is very much like the 300 by 11 foot simulation.

We also asked each pilot to answer a number of questions after all the runs were finished. They helped us evaluate the simulator, the experiment design, and the potential for simulation in training towboat pilots.

The major advantage of the computer simulation was that it gave precise, objective measurements of all the pilots' control actions and many measurements of what happened to the towboat. This allowed us to answer questions like:

Did the tow run aground?

Did it come close to grounding?

Could the pilot keep some reserve control at all times or did he (both pilots were men) have to use full rudder or all available backing power?

Did the tow often take up over half the channel such that two way traffic would be dangerous?

Could the tow complete the run with efficiency and economy?

Recommendations:

These results should be accepted as credible evidence that increased channel widths in bends, beyond the widths maintained at the time of this study, can substantially improve tow operating safety and reduce the risk of groundings on the Upper Mississippi River. The 300 foot channel width guideline should be applied only to those rare stretches that are literally straight. Even wide radius bends require about 400 foot controlling width; tighter bends require more.

The decision as to whether the substantial reduction in tow accident risk is worth the amount of added dredging required is a value decision to be made in each case.

For any section of navigation channel having much larger areas at minimum depth than this study investigated, additional consideration should be given to deepening the channel as well as widening it. Similarly, dredging decisions should be made with the realization that deepening straight segments could achieve substantially faster passage times.

To assure adequate attention to passing tow dynamics and to establish more firmly what benefits might attach to maintaining deeper channels in river segments of more uniform depth than the reach studied here, another simulator study similar to this one should be performed. Such a study should be designed:

(1) To determine what channel widths are sufficient to support two-way traffic under various flow conditions in straight reaches, large radius bends, and sharper bends, and

(2) To explore more conclusively the effects of channel depth on tow maneuverability.

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